09/485596
428 R PCT/PTO 11 FEB 2000
51 pgs.
[2345/113]

METHOD AND CIRCUIT ARRANGEMENT FOR TRANSMITTING MESSAGES

Field of the Invention

~~The~~ The present invention relates to a method and circuit arrangement for transmitting messages, the messages being coded by orthogonal functions to form a signal. ~~The invention also relates to a circuit arrangement for carrying out the method~~.

Related Technology

Methods as ~~of this type are known from the related art~~. Thus, in practice, frequent use is made of sinusoidal and cosinusoidal functions as orthogonal base functions for coding a number of messages to form a common signal. Reference is made to the book entitled *"Principles of Communication Engineering"*, Wozencraft, Jacobs, Wiley, New York 1965, which is herewith incorporated by reference herein, for the theory of these methods.

A2

The aim in transmitting messages is to make the signals to be transmitted immune to interference and to provide means at the receiving side which filter out interference.

Summary of the Invention

~~The~~ An object of the present invention is to specify a method and circuit arrangement which permit~~s~~ a high transmission rate in conjunction with a reduction in the interference susceptibility.

A3

~~This objective is achieved by~~ a method ~~having the features of Claim 1. Because so-~~called Hermite functions are used ~~as~~ orthogonal functions, the interference can be reduced substantially ~~at the~~ receiving side.

In an advantageous further development of the present invention, the received signal is subjected to a Fourier transform and subsequently decoded with the aid of the Hermite functions. In this case, use is made of the property that, except for a multiplicative constant, Hermite functions do not change during a Fourier transform.

An advantageous further development of the present invention provides for the received signal to be filtered before and/or after the Fourier transform, in order to eliminate

EL179105419

possibly included interference components.

In one advantageous further development of the invention, the received signal is decoded both in the time domain and in the frequency domain. That is to say, on the one hand, the received signal is fed directly to the decoding and, on the other hand, is first of all subjected to a Fourier transform and then decoded.

In an advantageous further development of the invention, in each case one of the two decoded signals in the time domain and in the frequency domain, respectively, is selected.

One advantageous further development of the invention provides for one of the two signals present in the time domain and in the frequency domain to be selected on the basis of all signals present.

The objective of the invention is also achieved by a circuit arrangement having the features of Claim 1. The circuit arrangement is designed for the purpose of carrying out the method according to the invention. To that end, at the transmitting side, the circuit arrangement has a modulation device which, with the assistance of Hermite functions, codes the messages to be transmitted. Provided correspondingly at the receiving side is a demodulation device which decodes the messages from the received signals with the aid of the Hermite functions.

In an advantageous further development of the present invention, the demodulation device has a number of multipliers, integrators and discriminators corresponding to the number of dimensions or linear factors, one multiplier, one integrator and one discriminator, respectively, being connected in series to form an evaluation unit. A multiplier and an ~~Multiplier and~~ integrator form a correlator.

In one advantageous further development of the invention, provision is made for a Fourier-transform device which subjects the received signal to a Fourier transform and

f~~eeds it to the evaluation units.~~

In another advantageous further development of the invention, each evaluation unit is provided in ~~duplicate, in which case one of the two evaluation units is fed the signal in~~ the time domain, and the other evaluation unit is fed the signal in the frequency domain. Instead of two evaluation units, it is optionally possible to use only one with a multiplex technique.

The present invention will now be explained in more detail on the basis of exemplary embodiments with reference to the drawing, in which:

Brief Description of the Drawing

Figure 1 shows a schematic representation of a first exemplary embodiment of a circuit arrangement;

Figure 2 shows a schematic representation of the receiving side of a further exemplary embodiment;

Figure 3 shows a schematic representation of the receiving side of a further exemplary embodiment;

Figure 4 shows a schematic representation of the receiving side of a further exemplary embodiment; and

Figure 5 shows a graphical representation of the first five Hermite functions.

Detailed Description

Figure 1 shows a circuit arrangement which is suitable for transmitting and receiving messages. It includes a transmitting device 3 which transmits signals to a receiving device 7, for example, via a transmission channel 5. Transmitting device 3 includes a plurality of, in the present exemplary embodiment, a number ~~of~~ L of multipliers 9, which, with the aid of orthogonal functions $f_0(t)$ to $f_{L-1}(t)$, map the message $\underline{m} = (m_0,\ldots,m_{L-1})$ to be coded. The output signals of multipliers 9 are fed to an adding device 11 which generates signal s(t) to be transmitted. Signal s(t) can therefore be represented as a linear combination of orthogonal base functions as follows:

$$s(t) = m_0\, f_0(t)+m_1\, f_1(t)+..+m_{L-1}\, f_{L-1}(t).$$

Functions $f_0(t)$ to $f_{L-1}(t)$ are orthogonal functions which satisfy the following rule:

$$\int_{-T/2}^{T/2} f_i(t) f_j(t)\, dt = \begin{Bmatrix} const & , i = j \\ 0 & otherwise \end{Bmatrix},$$

T being the orthogonality interval. Since the orthogonality interval of the Hermite functions extends over an infinite time interval, the Hermite functions must be approximated by technically realizable functions.

Functions f(t) are usually standardized in such a way that the constant is equal to 1. The term orthonormal functions is also used in this case.

It is indicated in Figure 1 that signal s(t) to be transmitted encounters interference on transmission path 5, the interference signal being denoted by e(t).

Receiving device 7 includes a number of decoder units 13 corresponding to the number of the dimensions contained in signal s(t). In the present exemplary embodiment, a number ~~of~~ L of decoder units 13 is provided. Each of decoder units 13 includes a multiplier 15, an integrator 17 and a discriminator 19. The aforesaid subassemblies are connected in series, the output signal of multiplier 15 being fed to the integrator, and the output signal of the integrator being fed to discriminator 19, which then provides the decoded component $\hat{m}_j$.

Each of decoder units 13 is fed a signal r(t) which is composed of transmitted signal s(t) and interference signal e(t). Owing to the orthogonality of the functions used for modulation, components m_j can be recovered from transmitted signal s(t) in a simple manner by calculating the integral

$$\int_{-T/2}^{+T/2} s(t)\, f_j(t)\, dt$$

This integration is carried out by integrators 17. Since signal r(t) received by receiving device 7 has an interference component e(t), the signal made available by integrators 17 in accordance with the equation

$$\int_{-T/2}^{+T/2} r(t)\, f_j(t)\, dt$$

where r(t) = s(t) + e(t)

also contains an interference component. The downstream discriminator 19 now has the task of determining the best possible estimated value for message m_j from the defective signal supplied by integrator 17.

In addition to the already mentioned property of orthogonality, functions $f_0(t)$ to $f_{L-1}(t)$ used for modulation are distinguished by the fact that they remain unchanged in the case of a Fourier transform, except for a multiplicative constant. Such functions are the Hermite functions, and are defined as follows:

$$f_n(X) = \frac{H_n(X)\, e^{\frac{-x^2}{2}}}{\sqrt{2^n n!}\sqrt{\pi}}$$

$H_n(x)$ being the Hermite polynomials, for which it holds that:

$$H_n(X) = (-1)^n e^{x^2} \frac{d^n}{dx^n} e^{-x^2}$$

A graphical representation of the first five Hermite functions is shown in Figure 5.

The strong exponential decay of the functions is clearly to be seen. This property permits, in a simple way, a technically realizable approximation of the functions which are then fed to multipliers 9 and 15. A detailed description of the mentioned Hermite functions can be found in the book entitled *"The Fourier Integral and Certain of Its Applications"*, N. Wiener, Cambridge University Press, Cambridge 1933, reprinted 1988.

Figure 2 shows a second exemplary embodiment of a receiving device 7, which corresponds essentially to the receiving device described and shown in Figure 1. A description of the parts marked with the same reference symbols is therefore dispensed with. By contrast with receiving device 7 already described, in the present exemplary embodiment, provision is made for a Fourier-transform device 21 which transforms received signal r(t) into the frequency domain and then feeds this transformed signal to multipliers 15. A first filter 22.1 is connected upstream of Fourier-transform device 21, and a second filter 22.2 is connected downstream of it. The schematically illustrated switches S are intended to indicate that the two filters 22.1, 22.2 can be used optionally. The two filters themselves are preferably low-pass or band-pass filters.

Because signal s(t) containing the message is represented in the base band as a linear combination of Hermite functions, this signal s(t) is essentially not changed by the Fourier transform of Fourier-transform device 21. The result of this is that decoder units 13 can be designed in accordance with the decoder units specified in Figure 1. Functions $F_0(f)$ to $F_{L-1}(f)$ fed to multipliers 15 differ from time functions $f_0(t)$ to $f_{L-1}(t)$ specified in Figure 1 only by a multiplicative constant whose value is equal to +/-1 or +/-i, i being the root of -1, provided that the Fourier transform is defined, as in the book by Wiener, as

$$F(f) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} f(t)\, e^{-ift}\, dt$$

Other definitions of the Fourier transform are likewise possible, mutatis mutandis. The definition used here is the mathematically simplest one in this case. Note, however, that the symbol f differs by a factor from the customary frequency.

The interference e(t) contained in received signal r(t) can be filtered out to a certain extent by filter 22.1 upstream of Fourier-transform device 21, the signal components of the orthogonal Hermite functions remaining essentially unchanged. A contribution to further reducing the interference component is made by second filter 22.2, which is connected downstream of Fourier-transform device 21 and eliminates further interference components by a further filtering operation.

A further exemplary embodiment of a receiving device 7 is shown in Figure 3. The design corresponds essentially to that of the receiving device according to Figure 2, so that a repeated description of the parts marked with the same reference symbols is omitted. In contrast with the above-named exemplary embodiment, in each case two units, composed of a multiplier 15 and integrator 17, are allocated to each discriminator 19. In each case, one of these units 23 is fed signal r(t) directly, while the respective other unit 25 receives the output signal of Fourier-transform device 21. The result of this is therefore a combination of receiving devices 7 shown in Figure 1 and in Figure 2, discriminator 19 being required to fulfil the task of selecting the best of the two fed output signals of integrators 17 and making it available as components $\hat{m}_j$. Discriminator 19 determines the best estimated value from the two fed signals in the time domain and in the frequency domain on the basis of a suitable metric, for example, the Euclidian metric.

Shown in Figure 4 is a further exemplary embodiment of receiving device 7 which corresponds essentially to the exemplary embodiment according to Figure 3. By contrast, in receiving device 7 according to Figure 4, a discriminator 19' is provided to which is fed the output signals of all the integrators 17 and which, on the basis of all the signals, estimates and outputs components m_0 to M_{L-1} using a suitable metric, for example, the Euclidian metric, once again. This receiving device makes it possible for

components $\hat{m}_0$ to $\hat{m}_{L-1}$, decoded from disturbed signal r(t), to have a very small interference component.

add B1

It is common to all the above-mentioned exemplary embodiments that an additional filtering can be performed in the frequency domain owing to the use of Hermite functions to code the message, because these Hermite functions are not essentially changed by the Fourier transform. Thus, interference in the decoded messages is reduced.

Of course, it is possible to combine individual exemplary embodiments; for example, the two filters 22.1, 22.2 shown in Figure 2 can also be used in the exemplary embodiments according to Figures 3 and 4. Moreover, it is conceivable for signal s(t) to be transformed into higher frequency domains in a known way by modulation. It is also conceivable for the exemplary embodiment shown in Figure 3 to be modified in such a way that, instead of two respective units 23, provision is made for only one unit 23 which is then alternately fed, via a multiplexer, the signal in the time domain and the signal in the frequency domain.